Blue Whale Behavioral Response Study & Field Testing of the New Bioacoustic Probe

Erin M. Oleson
NOAA-NMFS-Pacific Islands Fisheries Science Center
1601 Kapiolani Blvd. Ste. 1110
Honolulu, HI 96814
&
University of California San Diego
Scripps Institution of Oceanography
9500 Gilman Dr. #0205
La Jolla, CA 92093
phone: (808) 944-2172 fax: (808) 941-0307 email: erin.oleson@noaa.gov

John Calambokidis
Cascadia Research Collective
218 ½ W, 4th Ave.
Olympia, WA 98501
phone: (360) 943-7325 fax: (360) 943-7026 email: calambokidis@cascadiaresearch.org

Megan F. McKenna
National Park Service
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80521
phone: (970) 267-2123 email: megan.mckenna@gmail.com

John A. Hildebrand
University of California San Diego
Scripps Institution of Ocecanography
9500 Gilman Dr. #0205
La Jolla, CA 92093
phone: (858) 534-4069 fax: (858) 534-6849 email: jhildebrand@ucsd.edu

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LONG-TERM GOALS

Task 1: Blue Whales Behavioral Response Study
The behavioral response of large whales to commercial shipping and other low-frequency anthropogenic sound is not well understood. The PCAD model (NRC 2005) for assessing sound impacts on marine mammals calls for studies on noise source characteristics and the behavioral impact of specific sources on individual animals. Our goal is to understand the vocal and behavioral response of individual blue whales to high-intensity ship noise and close ship approach, resulting from the close geographic association between known foraging grounds and commercial shipping lanes off the coast

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of California. To accomplish this goal we deploy acoustic recording tags and GPS recording tags on blue whales within and near the shipping lanes while concurrently monitoring shipping traffic using the Automatic Identification System (AIS).

Task 2: Field testing the new Bioacoustic Probe:
Tagging studies of odontocetes have yielded incredible insights into the diving, movement, and daily activities patterns of several species. Missing from most of these studies has been information on the acoustic environment in which the animal is living and the sounds produced by the animals during different activities. Our goal is to use the new Acousonde to initiate studies of odontocete whale species in the Pacific Ocean. Although our aim is to address several scientific questions relating to diving behavior, vocal behavior, and swimming mechanics with the data collected during these deployments, the primary goal of this project is to conduct first field trials of the Acousonde with several species of cetacean and to refine the operation of the tag for robust field operation in the future.

OBJECTIVES

Task 1: Blue whale behavioral response study:
Our primary objective were this task were to determine how blue whales respond to close approach of ships and exposure to high intensity ship noise including changes in diving, feeding, and calling behavior.

Task 2: Field testing the new Bioacoustic Probe
The target specifications of the Acousonde include maximum depth of 3000 m, maximum sustained acoustic sample rate of 232 kHz, storage of 8 GB, 2 channels of acoustic data, and 3-dimensional accelerometer and compass. Our primary goal is to evaluate the functionality of the tag and to begin collection of vocal and diving behavior on a wide variety of odontocete species.

APPROACH

Task 1: Blue whale behavioral response study:
We evaluated the behavioral response of blue whales to intense ship noise and close ship approach using suction-cup attached acoustic recording tags and GPS Fastlock location tags. The proximity of shipping routes into southern and central California ports with predictable blue whale feeding grounds makes this an ideal location of the study of the impact of intense low-frequency noise on whale behavior. Field effort has been conducted for project since 2008. Past effort focused on the Santa Barbara Channel where shipping lanes pass through areas of frequent use by blue whales (Figure 1). Ship traffic use of the channel changed after the California Air Resources Board (CARB) rules in July 2009 mandating use of cleaner fuels within 24 nmi of shore resulted in many ships abandoning the shipping lanes through the channel (Law 2009). In 2010, we transitioned a portion of our operations to the shipping lanes off San Francisco near the Farallon Islands as predictable sightings of blue whales in the shipping lanes there made for an opportunity to work with both ships and whales. In 2011, we shifted our southern California effort further south, just outside the ports of Los Angeles and Long Beach where vessels taking varied routes around the Channel Islands converge, though are generally travelling slower (12 knots) than in areas further from the ports. In 2012, some of the commercial ship traffic returned to the Santa Barbara Channel and field efforts were split between the Santa Barbara Channel and the LA/Long Beach area.

Acoustic data collected by the B-Probe and Acousonde are analyzed to determine the presence and spectral characteristics of sounds produced by the whales and the ambient noise level prior to ship approach. Because of high levels of flow noise present in the acoustic tag records it is not always possible to measure the received sound level of the passing ship. During most behaviors the animal is swimming, therefore flow noise is usually high and broadband (150 dB and 0-1,000 Hz). For this reason most analyses are now based on ship proximity and speed, and with reference received levels measured for different ship types from seafloor recorders, rather than on the received level measured by the tag. Close approaches during quiet periods in the tag record do allow for direct measures of received level of the ship on occasion.

Dive depth and body orientation are measured by the sensors on the tag, and additional behavioral variables are derived from the auxiliary sensors, including acceleration, fluke rate, and feeding behavior, such as the presence of vertical or horizontal lunges. These behavioral measures are used to describe swimming mechanics, which may be used to derive energy expenditure (Goldbogen *et al.* 2006). Kinematic data for the tag deployments with a close ship passage of <1000 m prior to the 2011 field season were summarized and presented as deviations around the mean (or anomaly) in previous reports. Behaviors analyzed included dive behavior (duration, number of lunges), surface behavior (durations, number of breaths). Position data from the MK10 are used to evaluate fine-scale movements of the animals within and near the shipping lanes. Nighttime movements and behavior which cannot be effectively monitored by the research team are recorded on the MK10 for later evaluation of close ship approaches and behavioral changes during this period.

Task 2: Filed testing the new Bioacoustic Probe (Acousonde):
Tags are placed on various cetacean species off Southern California and Hawaii in conjunction with ongoing survey and tagging efforts. Off Southern California, our efforts are coordinated with visual and acoustic surveys underway as part of the SoCal BRS and our ship strike work (described as part of this report). Acoustic and dive data are analyzed as described above to assess the quality of the data collected by the new tag and to assess vocal and dive behavior of specific species.

WORK COMPLETED

Task1: Blue whale behavioral response study:
Deployments on blue whales in and around the Santa Barbara Channel shipping lanes have been conducted since 2008. During the 2011 season 26 tag deployments of four different types of tags were made on blue whales in and around the shipping lanes near the entrance to the ports of Long Beach and Los Angeles (Figure 1). These were primarily conducted in two dedicated time periods in August and October but included some tag deployments on two days in September conducted during the SOCAL BRS. These provided 142 hours of detailed data on blue whale underwater behavior, including 34 hours with detailed acoustics from the Acousonde, Dtags, and Bprobes and 108 hours with GPS-quality positions including through the night (four of these over 18 hour tracks). The detailed position data will be used to integrate with AIS tracks of ships to identify times, distances and behaviors of whales when ships were very close (Figure 2).

So far in 2012, field effort was conducted during one primary period from 22-29 August 2012 in the Santa Barbara Channel and off LA/Long Beach (Table 1). Additionally, four tags were deployed on 4-5 August 2012 on blue and fin whales in the LA/Long Beach near the shipping lanes as a part of the SOCAL-BRS. These deployments so far in 2012 provided 13 new deployments on blue whales and

one on fin whales and represented over 93 hours of data. These were split among three tag types: 9 Mk10 Fast loc GPS tags, 3 Dtags equipped with Fastloc GPS' on them, and 2 Acousondes.

While a few of these 2012 deployments were inside the shipping lanes most were just outside the shipping lanes. A primary goal of these deployments given the absence of a concentration of whales in the shipping lanes at the time of our work was to document behavior and in particular movement of animals feeding near the shipping lanes and whether they might move into or through the shipping lanes during the day or night. We were able to document night-time movements of these whales and some of these did show a pattern we had noted in past years with more directed movements at night that in several cases took them into the shipping lanes. Some specific accomplishments in the 2012 effort included:

1. Better night-time movement data of whales near (but not necessarily in) the shipping lanes
2. Two cases where we were able to tag both animals in a pair of blue whales to get data on synchrony of movements
3. Coordination with aerial observations of whale behavior at surface and during tag deployments.

Table 1: Deployments of tags during 2012. All were on blue whales except 8/4/12 11:48 deployment which was on a fin whale. Deployments on 8/4/12 were conducted as part of SOCAL BRS.

Deploy Date/Time	TagType	Region	Lat	Long	TagOff Date/Time	Hrs Total	Recover Date/Time
8/4/12 9:17	Mk10F	LA/Long Bch	N33 37.11	W118 14.99	8/4/12 11:38	2.3	8/4/12 11:38
8/4/12 11:58	Dtag/GPS	LA/Long Bch	N33 44.41	W118 26.00	8/5/12 7:17	19.3	8/5/12 9:13
8/4/12 12:51	Dtag/GPS	LA/Long Bch	N33 42.85	W118 23.87	8/5/12 8:25	19.6	8/5/12 9:58
8/4/12 17:05	Dtag/GPS	LA/Long Bch	N33 44.76	W118 26.14	8/4/12 19:22	2.3	8/5/12 7:50
8/22/12 12:07	Mk10F	SB Channel	N34 07.25	W120 01.30	8/22/12 15:00	2.9	8/23/12 10:27
8/23/12 13:18	Mk10F	SB Channel	N34 07.77	W119 52.44	8/23/12 15:35	2.3	8/23/12 15:55
8/23/12 13:39	Mk10F	SB Channel	N34 07.50	W119 52.83	8/24/12 0:50	11.2	8/24/12 9:25
8/23/12 14:14	Mk10F	SB Channel	N34 07.53	W119 52.97	8/23/12 15:24	1.2	8/23/12 15:37
8/26/12 12:56	Mk10F	LA/Long Bch	N33 32.83	W118 11.92	8/26/12 14:03	1.1	8/27/12 11:08
8/27/12 13:35	Acous	LA/Long Bch	N33 32.45	W117 50.83	8/27/12 22:17	8.7	8/28/12 14:55
8/27/12 14:58	Mk10F	LA/Long Bch	N33 30.44	W117 48.39	8/28/12 4:33	13.6	8/28/12 14:11
8/28/12 13:12	Acous	LA/Long Bch	N33 30.92	W117 48.79	8/28/12 17:09	4.0	8/28/12 18:17
8/29/12 11:35	Mk10F	LA/Long Bch	N33 27.53	W117 44.76	8/29/12 16:28	4.9	8/29/12 16:34
8/29/12 12:07	Mk10F	LA/Long Bch	N33 27.58	W117 44.84	8/29/12 12:23	0.3	8/29/12 12:25

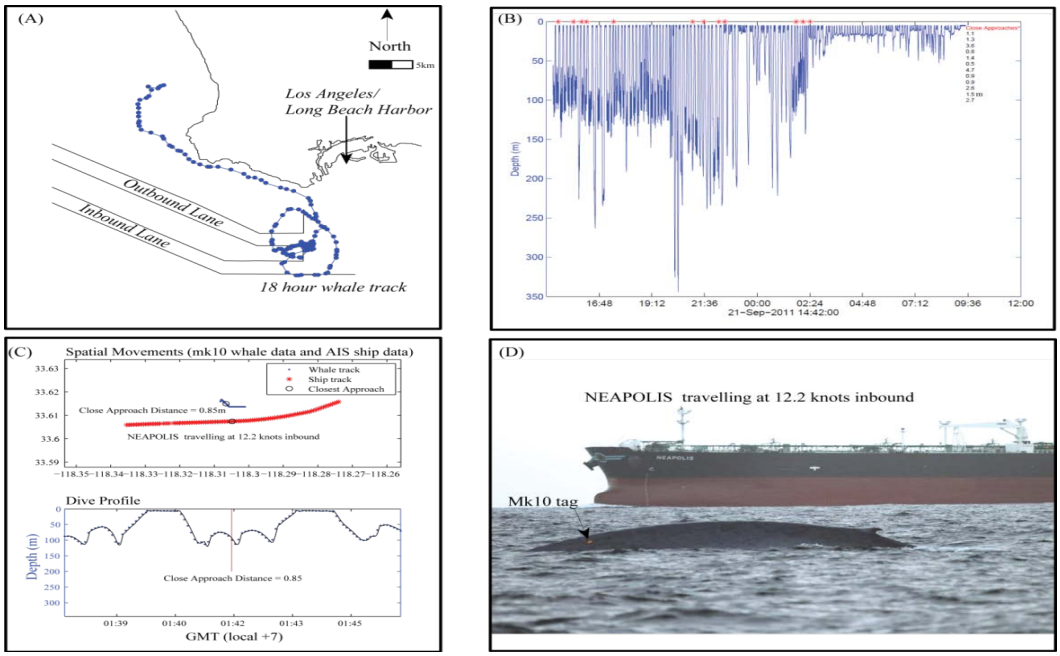

Figure 1: Mk 10 tag deployment on 21 September 2011 and examples of close approaches with large ships. The tag recorded for 18.6 hours. (A) Interpolated track of blue whale with Mk10 GPS tag points indicated by dots. (B) Dive profile of the whale with red stars indicating close approaches identified from combining mk10 and AIS data. The distances of each close approach are indicated on the right side of the graph. (C) A close approach event, both the spatial movements and the dive profile. (D) Photograph of the close approach shown in (C). The tag is visible on the back of the whale.

Task 2: Field testing the new Bioacoustic Probe

A type 3A Acousonde was delivered in summer of 2010 and was tested on blue whales off Southern California last summer and fall. In early 2011, the new streamlined form factor (3B) became available and two were made available for use during a number of field efforts for testing. Test deployments of the Acousonde 3A and 3B included one week of dedicated tagging effort off Kona, Hawaii in May, 2011, and opportunistic deployments on blue whales during our blue whale ship strike work in 2010-2012 (Table 2).

Table 2: Deployments of the Acousondes during field testing of sensors and attachment capability.

General location	Species	Date	Tag Type	Tag#	Hrs data	Comments
Snta Monica By, CA	Blue whale	22-Sep-10	3A	A012	14.9	
Gulf Farallones, CA	Blue whale	12-Oct-10	3A	A012	1	
Gulf Farallones, CA	Blue whale	13-Oct-10	3A	A012	1.3	
Kona, HI	Short-finned pilot whale	6-May-11	3A	A012	2.3	Power failed after 2 h
Kona, HI	Spotted dolphin	10-May-11	3B	B006	12	Filled acoustic storage 8.2 h
Long Beach, CA	Blue whale	15-Aug-11	3B	B006	-	Tag failed
Long Beach, CA	Blue whale	15-Aug-11	3B	B008	-	Tag failed
Long Beach, CA	Blue whale	16-Aug-11	3B	B008	9.5	
Long Beach, CA	Blue whale	19-Aug-11	3B	B008	2.3	Close ship approach
Long Beach, CA	Blue whale	3-Oct-11	3B	B008	1.7	
Long Beach, CA	Blue whale	4-Oct-11	3B	B008	1.6	
Long Beach, CA	Blue whale	4-Oct-11	3B	B006	0.6	
Newport Bch, CA	Blue whale	27-Aug-12	3B	B014	8.7	
Newport Bch, CA	Blue whale	28-Aug-12	3B	B008	4.0	

RESULTS

Task 1: Blue whale behavioral response study

Analysis of data collected to date has revealed several key results on how whales respond to close approach of ships (and exposure to ship noise):

1. An apparent lack of lateral avoidance to closely approaching ships even at 100-400 m.
2. Increases in surface times by some whales after close approaches by fast moving ships although no apparent increase in surface time in other areas with slower moving ships.
3. Increased time at surface and movement patterns of blue whales at night compared to the day indicating greater vulnerability to ship strikes at night (Figure 2)
4. We documented an avoidance dive of a blue whale in the path of an oncoming ship suggesting some vertical avoidance of ships but at a much slower decent rate than typically seen. This information has allowed us to model the relationship between reaction distance and ship speed required for whales to vertically avoid a collision (Figure 3).

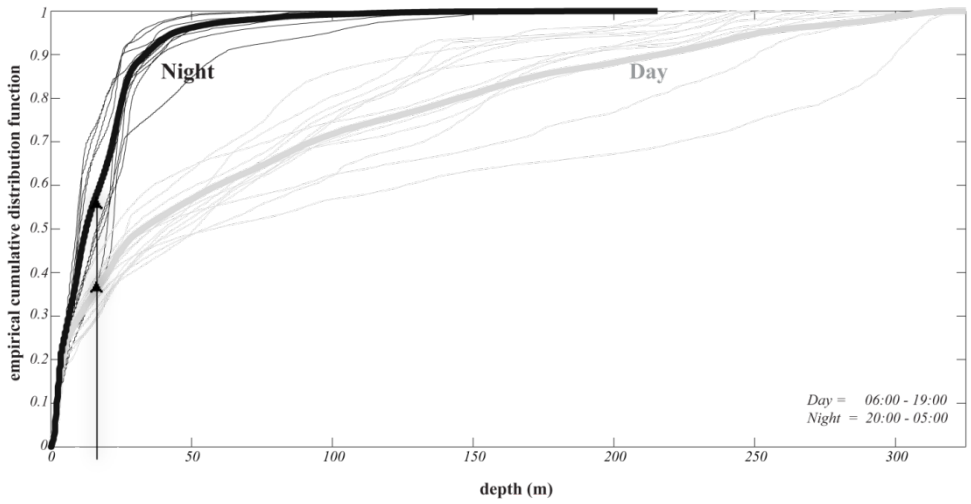

Figure 2: Cumulative distribution functions for the depth of the whales, given different hours of the day. The colors represent the different hours of the day. Arrows indicate average draft of a large ship (15 m) and the corresponding probabilities (0.35 for day and 0.57 for night).

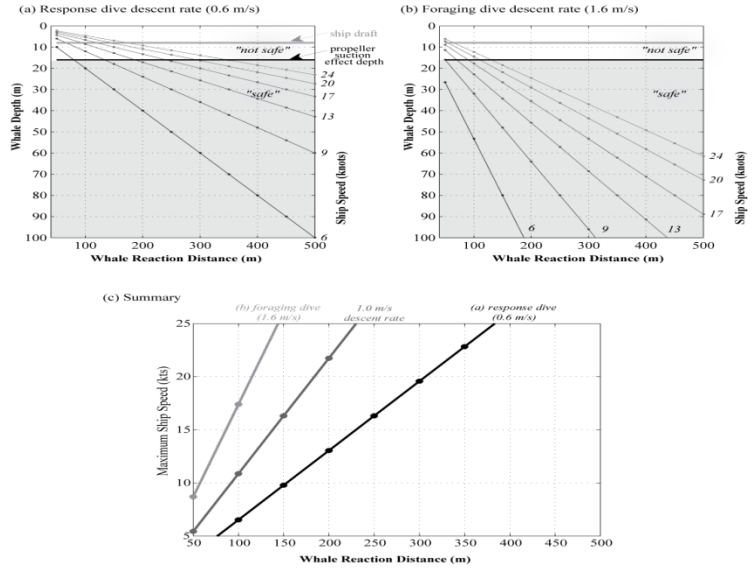

Figure 3: Modeled depth of whales considered safe from collisions based on reaction distances and ship speeds for descent rate of the response dive (a) and foraging dive (b). Curves represent different ship speeds. c) Distances at which whales would need to react to "avoid" collision with the ship as a function of different descent rates shown in (a), (b) and for 1.0 m/s.

Task 2: Field testing the new Bioacoustic Probe (Acousonde)
We have field tested the Acousonde during several missions off Califonria and Hawaii from 2010 to 2012 (Table 2). In work off California, three deployment of the 3A was made in 2010 and seven deployments were made of the 3B in 2011, all on blue whales, 2 deployments were made of the 3B in 2012 (see Figure 7 for an example depolyment with a blue whale A call recorded), all on blue whales. Several of the 3B attachments in 2011were short and may have reflected problems getting a good attachment due to the shape of the griper head holding the tag. This was modified for 2012 and the two deployments in 2012 resulted in intermediate attachment durations of 4 and 8.7 hours possibly reflecting better attachments. Data from attachement of the 3B in the shipping lanes provided data on ship noise, as discussed under Task 1. In May 2011, two deployments of the Acousonde were undertaken on odontocetes off Kona, HI. The first deployment of the Acousonde 3B on spotted dolphins was a huge success, as it demonstrated the benefit of the smaller and more streamlined form-factor of the tag. This deployment was the longest known suction cup tag deployment on a spotted dolphin and it collected very valuable data on the vocal and dive behavior of an individual spotted dolphin during intense troll fishing by 8 different fishing boats. The acoustic record of the tag includes not only the sounds of the tagged and nearby dolphins, but also the sounds of the various fishing boats as they passed over the dolphin school .

IMACT/APPLICATIONS

Task 1: Blue whale response to ships
The results of our tagging and monitoring studies are providing new information especially important for evaluation of ways to reduce the impact of ship strikes and ship noise. Our information on whale occurrence in and around shipping lanes has proved valuable in evaluating the placement of shipping lanes off southern and central California. In 2012 proposed changes to the shipping lanes leading to LA/Long Beach and San Francisco are going before the International Maritime Organization partly as a result of some of our data. Information on the behavior and movements of blue whales at night and how this makes them more vulnerable to ship strikes and their reaction to ships has been important in the evaluation of ways to reduce ship strikes including the 2012 recommendations of a Joint Working Group on ship strikes and ship noise (Joint Working Group 2012) that represents an ambitious plans for the reduction of ship strike and ship noise impacts on whales off central California.

Task 2: Field testing the new Bioacoustic Probe:
The Acousonde acoustic recording tag includes improved acoustic and auxiliary sensors. Animal orientation can be assessed in 3-dimensions, as well as dive depth, with all sensors capable of 10Hz sampling and some capable of sampling even more often. The new tag should be capable of providing valuable acoustic and dive data from medium to large odontocete cetaceans, a technological and scientific improvement over the previous tag technology. Some tag failures during our testing missions suggest some technical improvements are still needed.

RELATED PROJECTS

Task 1: Blue whale behavioral response study:
Several agencies and instutions have contributed to the greater goals of this project. Support has been provided by the Channel Islands National Marine Sanctuary who provided time on their vessel R/V Shearwater in 2009, 2010, 2011, and 2012. Additional funding has been provided by NMFS Marine Mammal Conservation Division. High-Frequency Acoustic Recorders (HARPs) have been deployed in the and around the Santa Barbara Channel by Scripps Insitution of Oceanography with support from

NOAA Fisheries Acoustics Program. The HARPs have provided valuable data on the spectral and sound level properties of individual ships (see publications list).

PUBLICATIONS

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